Forum paper

The integration of instructional systems design models and constructivistic design principles¹

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Abstract. This article first addresses the development of information and problem-solving procedures as “objectified” knowledge and the continuously increasing amount of it. For education decisions must be made which part of it should be passed on to future generations as obligatory for all members of a community or only for those persons who will prepare themselves for a special position. Then a description of instructional design is provided and the recent criticisms are discussed. This leads to an outline of an integrative framework for the description of information and problem-solving procedures and to a problem-solving approach for the acquisition of knowledge and skills. Three categories of problems are distinguished, categorization or description problems, interpretation problems and design problems. The solution of the many problems result in different cognitive constructs. Once these are published and selected for education they form the content of the subjects. For the development or construction of knowledge and the practicing of skills the learners should be involved in problem-solving activities, such as exploration, imagination, discovery, application and design. The required results of learning may differ. Three levels of performance, illustrated within the categories of problems are distinguished. It is shown that the content of the subjects and levels of performance can guide the selection of instructional strategies and make it possible to classify the learning situations. Finally some implications for curriculum design and for the selection of problems to be solved by the students are discussed.

Key words: constructivism, curriculum design, instructional design, instructional strategy, performance level, problem categories, problem solving

Introduction

The central idea in the theoretical position of constructivist scholars is that students construct knowledge for themselves (Winn, 1993) and that each person knows the world in a different way. In the extreme case this means that there is no shared objective world that can be analyzed for instructional purposes. There is much evidence that there is a need to know and that human beings actively develop or construct knowledge for themselves and that the world is known in different ways, but these differences don’t mean that reality cannot be “objectified”. For many centuries human beings have posed questions to reality, developed descriptions and explanations of reality,

discussed and verified the truth of these descriptions and explanations by making predictions. They developed procedures to answer the questions and became skilled in applying the procedure. Future physical events and future behaviour can be predicted, with or without interventions in the process involved. Moreover there is agreement about the way in which knowledge is “objectified”. Propositions, concepts and relationships between concepts are described in a standard way agreed on internationally. If there is disagreement about descriptions and predictions new knowledge is developed in systematic ways, such as by carrying out experiments. The knowledge is made public and stored as information and problem-solving methods. A person can read the thus externally represented knowledge. For long periods there can be agreement about the truth of a body of knowledge.

Human beings, organized in groups, communities or organizations have a need to pass on their knowledge and skills and the way to develop them to newcomers and members of future generations. The fulfilment of this need gradually developed into systematic education and an educational system. A few remarks on this process will clarify my position.

The amount of “objectified” knowledge has increased to such an extent that it is impossible for human beings to master all of it in their lifetimes. Moreover this knowledge is organised in conceptual systems and theories often in a hierarchical nature, which means that to master the knowledge a certain sequence in the mastery of concepts and theories is necessary. For education these points of departure have the following consequences:

First a decision has to be made about which knowledge will be passed on and whether it will be obligatory for all members of a community to acquire it or only for those persons who will prepare themselves for a profession or a special position in an organization. Once this decision is made, the curriculum, that is the organized content for a certain subject, has to be designed and the number of years necessary to master it has to be estimated. Then the students have to acquire the knowledge.

The problem for education now is how the students can develop or construct the “objectified” knowledge for themselves in such a way that it will be remembered, understood and used, that they can communicate about it with colleagues and teachers and that the process of development of the knowledge (and skills) will take place effectively and efficiently.

Instructional design

Instructional design comprises the task of the description and analysis of knowledge and skills, the sequencing of the concepts and theories, the design of the learning environment and the evaluation of learning results. During the

last three decades instructional-design theories and models have been developed and used. They provide techniques to describe and analyze “objectified” knowledge and skills in terms of types of content and learning outcomes and provide prescriptions about how to develop instructive programs and how to teach the content in order to reach the desired outcomes. The models are used as general heuristics to solve an instructional-design problem.

As has been said so often, and certainly by constructivists, instructional-design theories and models have some shortcomings – they have some features that may be useful for the designer, but have consequential problems in learning situations.

In the first generation models, that were developed in the 1970s and 1980s by Gagné and Briggs (1979), Merrill (1983) and Reigeluth and Stein (1983) the outcomes of instruction or categories of learning (e.g. discrimination of concepts, use of procedures, application of principles, etc.) are isolated as such and instructional-design rules are formulated for each such category. The problem is that a coherent piece of information will often contain more than one instructional outcome. The general limitation of most existing ID-models and methodologies is that their unit of analysis leads to isolated instruction for limited pieces of knowledge. There are no instructional prescriptions how to integrate the units and how learners can flexibly use them in solving problems. Thus instructional models for learning a rule, such as a general law, do not include rules about to integrate earlier learned concepts.

A second feature of the traditional models is their emphasis on what the designer and teacher should do. The content of a subject is analyzed and divided into types of content. Tasks are analyzed into subtasks. Then the prescriptions for the design of instruction are applied. The approach leads to emphasis on content structure and analysis techniques and to the presentation of information. This may take away the designer’s attention from the students’ learning activities, how these activities are made possible and in which situations the knowledge and skills will be acquired optimally. More emphasis on the learners’ manipulation and interaction with the relevant objects is necessary for understanding and using knowledge in different situations; thus, the instructional-design models should better prescribe which situations will optimally support the learner to develop knowledge. Those situations are labeled problem-solving situations. In a problem-solving situation the learner can be invited to develop or construct knowledge and problem-solving procedures. The learner’s activities in a problem-solving situation more or less should resemble the activities of those persons who originally constructed the knowledge by solving a problem, that is by answering a question for which the answer couldn’t be given immediately and for which a number of steps had to be carried out or first developed. A learning environment will be productive

for learners if they are required to solve problems and if the environment helps to monitor the students and provide information when necessary. In a problem-solving situation learners need information, which can be provided in advance or be presented if the learners ask for it, but sometimes it is better that the learners try to find the information themselves, do measurements and as a consequence discover regularities.

Presentation of information should not prevent the learners' activities. In order to construct knowledge the learners need to solve problems. Then the learners will be active, do things, construct a sequence of operations to reach a goal. The solution of a problem leads to the construction of knowledge and problem-solving procedures. If the procedures are often used a skill is learned and practised. Different categories of problems will lead to different types of knowledge and skills. For the development of an instructional-design model or for the change of existing models first a categorization of problems into different types is made. For each type the knowledge and problem-solving procedures are outlined. These are used for the design of learning environments which provide opportunities for the students to construct or develop the knowledge and skills.

An integrative framework

From the above criticisms, it becomes clear that ID-models need to be extended through the creation of an integrative framework for the design of instruction which can be used both in schools and in industrial and other sectors, and which covers the tasks in as many domains as possible. The integrative framework should include a description of the subject matter (i.e., content) and the goals to be reached. Further it should provide guidelines to instructional designers how to select the types of problems or cases one should confront learners with in order to reach particular learning goals. Finally it should make clear how to reach these exit behaviors performed at pre-defined levels of performance. The development of the framework is outlined underneath.

The stored content of the description and interpretation of the real-world is a result of human activities the most relevant of which are observation, exploration and discovery, imagination, research and development. If these activities are carried out in an unclear situation in which it is felt that something is missing and if the activities are done in a systematic way the activity is labelled problem solving. The result of the activity is the construction of new knowledge and skills, or, cognitive constructs. If these are externally represented in written or other formats they make up the content of a subject as information and problem-solving procedures.

Figure 1. Three types of problems and their relationships.

Problem-solving behavior or construction of knowledge and skills is general for human beings. Due to developmental variables and also time constraints in education this behavior is distinguished in different levels of performance.

Types of problems. As indicated in Figure 1, the three types of problems distinguished are (a) categorization or description problems, (b) interpretation problems, and (c) design problems. For categorization problems, instances must be assigned to categories. The cognitive constructs resulting from such problem solving activities are concepts (both class- and relational), conceptual networks, or descriptive theories (The label theory is used to indicate the organized body of knowledge about a domain created as a result of reflection on entities and phenomena and the analysis and construction of entities and phenomena).

For interpretation problems, relationships between concepts must be identified. It should be clear that concepts are basic to principles, as reflected in Figure 1. The cognitive constructs resulting from the solving of interpretation problems are principles, causal networks, or explanatory theories. In contrast to descriptive theories, explanatory theories not only describe regularities (i.e., allow for predictions) but also provide deeper understandings of the mechanisms involved.

For design problems, artifacts must be created. Again, concepts are basic to the solving of design problems. As discussed before in the context of problem

solving in ID, the cognitive constructs resulting from design problem solving are plans, procedures, or prescriptive theories.

Though it is possible to distinguish the three categories of problems theoretically, they usually appear in combination – as indicated by the links in Figure 1. For example, an interpretation problem always concerns concrete or assumed objects (e.g. plants and insects, molecules and atoms) whose concepts are the subjects of research. For the solution of an interpretation problem a device or measurement instrument often has to be designed. And for the design of an object the results of interpretation problems will often be used.

The problems of the three categories may be further distinguished in degree of well- and ill-structuredness, complexity, generality and abstractness. A well-structured problem is a problem the solution of which can only be right or wrong, whereas the solution of an ill-structured problem can only be better or worse. The degree of complexity of a problem is related to the amount of knowledge involved and to the number of operations required for the solution. The degree of generality is related to all objects of a category or taxonomy of categories, whereas the degree of abstractness means considering objects and their relationships while looking away from their empirical existence.

In education, the cognitive constructs resulting from the exploration, discovery, imagination, research and development activities described above may be seen as the content of the subject matter. If activities such as exploration, research and design are performed, human beings learn and develop (construct) knowledge and skills. Does this mean that all the exploratory, problem-solving and design activity has to be replicated by the learners? It is simply impossible. For education, an ultimate goal may be the independent formulation and solution of both theoretical and practical problems by learners as part of their self-actualization, but this level of performance can only be reached for a minority – the members of which wish to, and are able to, reach that goal. Further it can only be reached for a limited subject and after many years of prerequisite training.

Several other goals at a lower level of performance and more or less derived from the ultimate goals are distinguished, such as (a) the acquisition of knowledge and skills to function easily in the everyday situation and (b) knowledge and skills to do a job at a certain level of performance. For example, the first set encompasses goals such as the use of basic arithmetic procedures, reading, writing and retrieving information from different sources. Within the second set the procedures of the job will be practiced. For example secretaries will not be interested in which programming language the word processing program is written in, but they wish to know which commands are necessary to make and change a document, save, retrieve and print it.

Figure 2. Three levels of performance for the three types of problems.

Though it is impossible in education to replicate all human activities which produced information and problem-solving procedures, it will also be clear that it is important that some part of the exploration, problem-solving and design activities are replicated. This is an important decision to be made by the instructional designer. For the selection of the curriculum content the current usefulness and the ease of transfer of knowledge and skills are important criteria. Moreover the representativeness of experiments and artifacts for a subject, and the general usefulness of a skill, contribute to the selection of the content.

Levels of performance. Exploration, imagination and original problem-solving activities result in information which will be used to solve more problems. In education, part of this information will be acquired as knowledge and skills. Both should meet the criterion that they are understood. For the knowledge and skills to be acquired this means that first the situation in which the skill can be executed must be recognized and that, if necessary, the procedures can be applied and the predictions tested. The tasks to be performed will resemble the original task as much as possible; that is, working towards authentic tasks is considered to be important. It is supposed that knowledge and skills are acquired in a simultaneous process. The acquisition of knowledge and skills can be separated but then they have a chance to be learned by rote and are less transferable.

As indicated in Figure 2, three levels of performance can be distinguished for each of the three categories of problems: (a) remember, recognize and imagine, (b) apply, use, and predict, and (c) construct, create, and invent. At the lowest level of performance, both examples of the solution and the procedure to reach a solution are available for the learners. For instance, a categorization problem to be solved may be to categorize trees as either coniferous or deciduous trees. Prior to problem solving, the features of these categories of trees are presented and examples of both are provided (e.g. branches with different leaves). The cognitive constructs resulting from such an activity are mainly concepts (i.e., the concepts conifer and deciduous tree). As another example, a design problem to be solved may be to finish some instructional materials developed according to a particular ID-model (e.g., Merrill's Component Display Theory, CDT, 1983). In addition to the procedure to develop the materials (i.e., CDT), other instructional materials offer concrete examples or analogies of characteristics of a good solution. The cognitive constructs resulting from such an activity are mainly plans (e.g., let presentation precede practice, accompany a generality with at least two examples, use multiple representations for difficult content, etcetera).

At the middle level of performance, only the procedure to reach a solution is given. For instance, a categorization problem to be solved at this level might be to categorize all conifers in families. The given procedure is to list as many conifers as possible, to list the features of those conifers, and to group the trees with common attributes. The cognitive constructs resulting from such an activity are conceptual networks. As another example, a design problem to be solved at this level might be to design instructional materials according to a particular theory where no clear analogies (i.e., solutions for similar problems) are available. The cognitive constructs resulting from such an activity are mainly procedures, or, algorithms and heuristics to solve new ID problems.

At the highest level of performance, neither examples of an analogous solution nor the procedure to reach a solution are available for the learners. For instance, a categorization problem given at this level might be to develop a system enabling others to categorize trees. The cognitive construct resulting from such an activity (as, for instance, performed by biologists) is a descriptive theory or system. Finally, a design problem to be solved at this level might be to develop an ID-theory for interpersonal skills training, based on a literature study and experimental research. The cognitive constructs resulting from this activity are prescriptive theories; in fact, it is the activity many instructional technologists are involved in.

Designing learning situations for the construction of knowledge and for practicing skills

The analysis of tasks and domains in terms of learning objectives and the selection of problems forms the basis for the design of instruction, learning environments, and instructional materials. In the previous section, three types of problems to-be-solved by the learners, offering different types of “content”, and three levels of performance for problem solving activities to-be-performed by the learners, were distinguished.

In this section, it will be shown that content and performance level can guide the selection of instructional strategies and tactics and make it possible to classify the learning situations for which so many well-known labels are available. Second a few remarks will be made on curriculum design.

The selection of instructional strategies. The nine categories of problem solving activities that are distinguished correspond with nine categories of instructional strategies. At the lowest level of performance, *learning by examples* is considered to be a core aspect of the problem solving activities the learners are engaged in. Instructional strategies and tactics at this level of performance should make ample use of examples (i.e., exemplary solutions) of the problems-to-be-solved and provoke mindful abstraction from those examples. For instance, learning to classify is illustrated by presenting or showing examples (e.g. trees are observed in parks and woods, with branches and leaves available for the students. The way they reproduce is illustrated and why they are important for life on earth and for humans is made clear).

For instance, interpretation problems presented to learners at this level might be to predict a particular event (e.g., how long will it take for a ball dropping from a height of 10 metres to reach the surface of the moon) where an analogous solution (e.g., the computation for dropping a ball on earth) is available (cf. the “worked examples” approach of Paas & Van Merriënboer, 1994). As another example, design problems at this level presented in a computer programming course might be to complete, adjust, or extend existing computer programs – forcing learners to study (partial) solutions carefully and so build a repertoire of so-called programming plans (Van Merriënboer, 1990; Van Merriënboer & de Croock, 1992).

At the middle level of performance, *learning by doing* is the central aspect of the problem solving activities the learners are engaged in. Instructional strategies at this level of performance should concentrate on the construction of categories, explanations, or artifacts. For instance, interpretation problems presented to learners at this level of performance might be to conduct a series of well-described experiments (i.e., the procedure to reach a solution is given) in a simulation environment in order to reach a description of rela-

tions between a number of variables. Or, in a computer programming course, design problems at this level might be independently to design and implement computer programs, according to a particular structured programming approach and using a particular programming language (the so-called “expert approach”, Van Merriënboer & Krammer, 1987).

Finally, at the highest level of performance, *learning by exploration and experimentation* is the core aspect of problem solving activities the learners are engaged in. Instructional strategies should concentrate on original problem solving activities and theory-building based on exploration and experimentation. For instance, interpretation problems presented to learners to reach this level of performance might confront them with a – simulation of a – process, and the assignment to identify and describe the variables and relations between variables in this process – in order to be able to explain what is going on. Thus, learners have to design their own experiments, to steer their own explorations, and to do their own research to reach an explanatory theory. Or, in a computer programming course, design problems at this level might be to design a top-down design model for programming or a new programming language that should meet a number of requirements.

All these strategies are designed such that the students have to be active, answer questions and solve problems. In this way they have ample opportunity to construct knowledge for themselves. These opportunities also function for providing feedback because the students have to be active and produce behavior. They also function as tests to check whether the answers and predictions are correct because the reality provides the feedback.

Curriculum design

Information and problem-solving procedures, organized in conceptual systems, theories and design rules and procedures, are continuously developing. To understand the conceptual systems, theories and procedures, the relationships between components must first be analyzed. Those concepts and parts of theories and design procedures that are necessary to understanding other concepts and parts of theories have to be identified.

This can be done for the concepts and theories of the empirical and formal sciences separately. But often the concepts and problem-solving procedures of the formal sciences (mathematics, informatics) are necessary to accurately describe the concepts and problem-solving procedures of the empirical sciences and their applications (e.g. physics, economics, mechanical engineering). In this situation the analysis should be done for both subjects in combination. In both cases the analysis leads to one or more hierarchies or other networks of concepts, theories and procedures. The conceptual systems,

causal structures and prescriptive systems are directly related to the problem-solving procedures that made the development and test of the theories possible. In this way the development of knowledge and the learning of skills cannot be easily separated. If they are separated, which happens in those situations in which the teachers only present information for a long period, knowledge construction is difficult to realize or even impossible and rote learning may occur.

Though the condition of simultaneously developing knowledge and skills is generally accepted in education, in everyday school practice many constraints are of influence. For example, to learn the content of mathematics and computer science those persons who develop the high school curricula and the teachers who use the curricula agree that learners should solve many problems. These can often be solved by paper and pencil, by the use of a calculator and a personal computer. For the empirical sciences, such as physics and chemistry, solving problems is much more difficult to organize, because the learners need a special device and a sample of matter to study physical or chemical properties. Much depends on the available equipment and on the skill of the teachers to organize the problem situation for all the learners. For other domains, such as language and history, also problems will be formulated. How to translate a text, to interpret a text and how to find the meaning of a historical document leads to problem-solving activity that develops knowledge and skills.

Thus for the design of a curriculum the dependencies between components of the content have to be analyzed and the assumptions and basic concepts described. This doesn't mean that the whole content of a subject should be taught, but it means that the dependencies between components should be clear in order to make understanding possible.

Once the components are analyzed the decision has to be made about which problems, and how many problems, the students should solve. These are the key problems of a subject, the solution of which has led to new concepts, progress in theories and to new design techniques.

Of course practical and economic constraints lead to learning situations that are less authentic and to the use of simulations, but the choice of key problems is most important. The number of problems to be solved depends on several criteria, the most important of which are the level of abstraction and complexity of the knowledge, the importance of the skill for life and the complexity of the skill involved. The description of mastery criteria take these conditions into account. Other variables also are considered for the knowledge and skill involved, such as the intelligence of the students. The decisions about how many problems to solve are usually taken on empirical evidence.

Conclusion

The problem for education as stated in the introduction, is how the students can develop or construct the “objectified” knowledge for themselves in such a way that it will be remembered, understood and used, that they can communicate about it with colleagues and teachers and that the process of development of the knowledge (and skills) will take place effectively and efficiently.

The solution of this problem is to promote the students’ involvement in a knowledge construction process by continuously presenting problems which require them to make categorizations, interpret phenomena and design artefacts. This should be done for different levels of performance and for all the curriculum subjects involved.

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